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# The scientific disciplines: what comes first among equals?

*James D. Williams*

**ABSTRACT** The UK Government has considerably increased its targets for recruiting chemistry and physics teachers, with a view to increasing the number of students taking separate sciences and to boost science uptake post-16. This article charts the establishment of the science disciplines, rejecting a hierarchy of subjects and the simple splitting of science into three disciplines. It argues that science teacher education (training) should be lengthened to allow science graduates to develop their knowledge and understanding of a wider range of disciplines and calls for the implementation of the teaching of a coherent and inclusive form of natural sciences to the age of 16, with specialisms taken only beyond that age.

Science has a central role in the education of children aged 5–16 with the UK coalition Government that was elected in May 2010, maintaining its place as a core subject. There are, however, concerns over what science is taught, how it is delivered and by whom. The education secretary, Michael Gove, expressed concern over the numbers of specialist physical science teachers entering teacher education. Consequently, high targets were set for the 2011–12 recruitment cycle (925 physics and 1070 chemistry trainees), while the numbers recruited to ‘other’ sciences, including biology, were significantly reduced.

The act of separating the physical sciences for teacher training purposes with bursaries linked to degree classification creates a false hierarchy. Physics and chemistry attract a bursary of £20,000 for a first-class honours graduate, £15,000 for a 2:1 and £12,000 for a 2:2 degree. There is no bursary for biology or general science, relegating these disciplines to a state of oblivion. The new bursary payment rules also allow for a person with, say, a first-class geography degree who undertakes a 6 month subject knowledge enhancement programme in physics to be paid £20,000 and be classified as a physics specialist.

Competition between those who see themselves as physicists, chemists or biologists can lead to interesting ‘science staff banter’. This may well involve the idea that physics is the ‘senior’ science and that, without physics,

other sciences would struggle. Chemistry, derived from ancient alchemy, could be next in such a hypothetical ordering, followed by geology – although this plays a minor role in science teaching in schools – and ultimately the ‘baby’ of the science family, biology, with its formal establishment in the early nineteenth century and its ‘big idea’, evolution, coming with the publication of Darwin and Wallace’s ‘theory of evolution by natural selection’ in 1858.

An alternative argument for a hierarchy of sciences could be derived from the content of the disciplines. For example, many processes in biology are chemical in nature. Many chemistry processes can be explained through physics and the principles of physics. This brings us again to the idea that physics is at the heart of all science and, in a reductionist view, is the one true ‘senior’ science.

A report by the Institution of Engineering and Technology (IET) charts the decline in the uptake of science, technology, engineering and mathematics (STEM) subjects (IET, 2008) and identifies a number of barriers that prevent pupils taking up science subjects post-16, the major barrier being a lack of inspirational teaching. More recent indicators show that uptake to post-16 STEM subjects is increasing (NFER, 2011)

A useful question to bring up at this point is whether the correct solution to the poor uptake of science is to focus solely on training subject specialists as science teachers. Certainly, if the

curriculum reinforces the notion of separate sciences it would be difficult to argue that having science specialists would not aid the teaching of these subjects. In reality, however, the school science curriculum is likely to contain a mixture of five or six separate disciplines in science including, as well as the traditional 'three' already mentioned, geology, astronomy and some psychology. Perhaps it is time to radically change our concept of the scientific disciplines in school and turn to teaching 'natural sciences' to the age of 16, leaving the division of science into its constituent separate disciplines until post-16. An alternative view may be that, with the Government initiative of a 'broad and balanced science curriculum for all' in the mid-1980s (DES, 1985), this approach has been implemented but has not succeeded. Our current science provision, derived from broad balanced science, is a more or less 'one size fits all' curriculum that seeks to serve widely differing outcomes, from an initial training for those set on higher qualifications and careers in science subjects to delivering a curriculum that achieves scientific literacy for those who decide, for whatever reason, not to study science formally beyond the age of 16. It may be this that is more responsible for the lack of success in science uptake post-16.

### Science as a human construct

Humans are inquisitive and we ask 'why?', whereas animals, to the best of our knowledge, do not. We investigate the underlying causes of natural phenomena – we seek explanations of the natural world and that is one definition of science. We ask scientific questions: Why does each year have seasons? Why does the Earth appear to be motionless and the Sun revolve around it? Why do different types of animals and plants live in different habitats?

What we are doing often is linking cause and effect: if this happens, then this results. Crucial to that linking is the idea of prediction. We try to hypothesise from our observations of nature and natural phenomena and then generate predictions of events and processes. Alongside such activities as observation, hypothesis generation, prediction and experimentation, we investigate the properties of the natural world. Chance happenings, serendipitous events, systematic exploration and experimentation have all played their part in the history of humankind and the history of science (Williams, 2011).

The separate disciplines of science are not natural disciplines but ones that humans have created. In nature there is no differentiation between biology and biochemistry, physics and quantum physics. Humans have, over thousands of years, developed and compartmentalised knowledge to form the disciplines we call science. Some aspects and areas in science are relatively recent innovations. For example, the formal science of 'biology' was only named as such in the early nineteenth century, by Jean-Baptiste Lamarck (Coleman, 1977), but that was not the start of the study of living things. Natural history, botany and zoology have all had a place at various points in the history of science. Aristotle first began describing and classifying living organisms in Ancient Greek times. Today, 'new' sciences, such as nanoscience, are established with their origins being relatively well documented. Each scientific discipline has a history. In an earlier article (Williams, 2007), I described a brief history of science from the Ancient Greeks through to the 'scientific revolution'. Science, as a human endeavour, did not begin in Ancient Greece; it stretches much further back into human history.

### Magic or science?

For ancient humans, the distinction between magic and science would have been non-existent. Evoking prayers or performing rituals to encourage rain for crops to grow or appeasing 'the gods' with the slaughter of animals, even humans, to prevent natural disasters looks silly, even barbaric, to modern civilisation. Making connections between volcanic eruptions and upsetting some mythical supernatural being has no place in science today. Yet although we understand the broad mechanisms whereby plate movements can cause volcanic eruptions, we still cannot, with any degree of predictive power or accuracy, know when an eruption is likely to take place. Devastating events, for example in Japan, Haiti and Chile where large earthquakes caused immense damage, tsunamis and the deaths of hundreds of thousands of people, can still have modern communities offering prayers for the survivors and for those who tragically lost their lives. So just what is the difference between offering prayers to a god to prevent a natural disaster and offering prayers for the survivors of a natural disaster? We may laugh at

the shaman performing a rain dance and glibly say that meteorology is a far better way of predicting when the rains may come for the crops, yet meteorology's record in accurate long-range forecasting is not good (Derbyshire, 2010).

What made the magicians of ancient times successful is probably their ability to observe nature and to form reasonably accurate short-term predictions. Their predictions need not have been 100% accurate. Look today at generalised predictions in astrology and consider how many people subscribe to their future being foretold 'in the stars' and it is easy to see that a shaman or ancient mystic needed only to be marginally better at making predictions than the general population, to be seen as 'magical'. We could think of the shaman or mystic as a type of scientist observing the natural world, forming hypotheses, making predictions and, should their predictions be correct or nearly so, refining and confirming their original finding and moving towards an explanation – a 'theory' – for that natural phenomenon. In a classic article, Horton (1971) claimed that African traditional thought was best understood as constituting a body of theory whose fundamental aim, like that of Western science, was explanation, prediction and control of the phenomena of everyday life.

### Early physics

What we now refer to as 'physics' combined the study of such things as astronomy, mechanics and optics. Essentially, it was a mathematical discipline. The ancient Babylonians would observe the stars and their apparent movement. Ancient Greek philosophers, such as Archimedes and Ptolemy, continued this tradition. The 'physics' of the day tried to be explanatory, rather than merely descriptive. This, in itself, promotes the study of such phenomena to a 'science'; that is, an explanatory rather than simply a descriptive process.

### Metals and the origin of chemistry

The early metallurgists of the bronze and iron ages could register a claim to be thought of as early chemists. Their knowledge and understanding of the chemistry and extraction of these metals from the rocks in which they were found was by no means a systematic and considered process that followed the conventions of how chemists today would operate. Exactly how these civilisations discovered and modified the process of extraction

is unknown. The most likely 'method' was trial and error – basic experimentation.

### Prehistory medicinal science

Early humans observed that certain plants could be used to treat sickness and disease. They developed herbal medicines and with the domestication of animals and the routine growing of crops came knowledge and understanding of disease. Neanderthal burial sites, with flowers and medicinal plants found associated with the body, have been documented (Solecki, Solecki and Agelarakis, 2004). Even the famous ancient 'iceman', Ötzi, found mummified in the Italian Alps in 1991, carried birch fungus, which can be used as an antibiotic (Dickson, Oeggel and Handley, 2003). Domestication of animals started around 7000 BCE and it is reasonable to assume that the early farmers saw and treated many animal diseases and injuries. Such treatment may have come from the early treatment of other humans or vice versa.

A very early surgical procedure was trepanning (also known as trephining). It involved the drilling of a hole in the skull to treat a variety of ailments. Evidence of trepanning has been found in prehistoric human remains, going back to 2000 BCE, with a female skull discovered in Armenia that had a 2.5 cm hole plugged with animal bone. Evidence of active growth around the bone plug and hole show that the patient survived the 'surgery' (Prioreschi, 1991). Trepanning and herbal medicine were probably not the result of scientific endeavour as we would appreciate it today. Drilling holes in the skull to 'release demons' (one reason that trepanning is thought to have been practised), when the 'demons' were probably epileptic fits, was unlikely to have been the result of a scientific investigation of epilepsy and how to prevent it. Modern science does not advocate trepanning as a cure, with most forms of epilepsy being treated with some form of medication, although invasive brain surgery – a major step beyond trepanning – is also used in extreme cases.

### Science teaching in British schools

William Sharp (1805–1896) is credited as being the first 'public school' (see Note at end) science teacher. Sharp, a physician and homeopath, was born at Armley, near Leeds. In 1826, he was licensed to practise by the Society of Apothecaries

and he became a member of the Royal College of Surgeons in 1827, working as a surgeon at Bradford Infirmary. In 1847, after a short period living in Hull, he moved to Rugby so his sons could attend Rugby School. He persuaded Dr Tait (the headmaster) that science should be taught to the boys. He was given the post of 'Reader in Natural Philosophy', though he left in 1850 to devote more time to medical research (Leary, 2004).

The foundation of science as a taught subject in all British schools came with the publication in 1867 of a report entitled *Scientific Education in Schools* by the British Association for the Advancement of Science (BAAS). The report defined science education as consisting of chemistry, biology, physical and mathematical sciences, and geology. The resultant curriculum marginalised issues and values related to everyday life. It was an attempt to promote 'pure science' and detach it from technology – the application of scientific knowledge to solve problems. As well as promoting 'pure science', the report also emphasised the teaching of scientific thinking with the aim of an education in science being capable of promoting a public understanding of science and delivering pre-training in science to meet the needs of industry for qualified scientists and technologists. The BAAS report made a clear distinction between these two possible outcomes, with the latter outcome becoming the driving force for science education in schools (Layton, 1981).

Many of the more recent changes to the science National Curriculum can be interpreted as an attempt to redress the imbalance between education for 'scientific literacy' and as a training ground for future scientists and technologists, with a move towards a curriculum that leads to 'scientific literacy' (though there is insufficient space in this article to discuss what we mean by this term), public understanding of science and scientific thinking. The move to deliver the 'facts' of science through teaching about the process of science, or 'How science works', clearly highlights aspects of scientific thinking, moral and ethical issues in science, and argumentation skills, without ignoring the investigative and experimental skills needed for practical science. This is, in some ways, a return to the roots of science as a school discipline as described in the BAAS report of 1867.

Early science education in schools was not necessarily of high quality, taught by specialists, or

well organised. It has been described as 'chaotic' (Timmons, 2001). It was not until the Education Act of 1902 that the delivery of science in an organised way was really tackled. Even then, the teaching of science in elementary schools was rare.

Problems with the teaching of science were not restricted to a lack of understanding of what content should be taught, or that science should be delivered as 'pure science', free from social considerations. There was also a distinct lack of specialist teachers who could deliver it in schools. Science teacher education was very restricted – being mainly in London – and those who could freely enter teaching with little or no teacher training (that is, graduates in the natural sciences from Cambridge or Oxford) were not in great supply. There were few textbooks, facilities were very limited and it was expensive to deliver (Timmons, 2001).

Science education in schools has evolved from a subject that was wide ranging (taking in mathematics as well as geology) and where the aim was to deliver 'pure science' to a subject that is today conventionally cited as 'biology, chemistry and physics' where teaching scientific thinking and the process of science should be just as important as learning the 'facts' of science in the form of content knowledge.

The 2011 review of the National Curriculum was heralded by comments from central government that indicated a return to more 'traditional' science teaching and learning, concentrating on content knowledge, not to the exclusion of process, but with such knowledge playing a more central role in the curriculum and subject specifications.

### The case for 'natural sciences'

One of the architects of nineteenth and early twentieth century British school science was Thomas Henry Huxley (1825–1895). In his book *Science and Education* he outlined his vision for science education and what should be taught (Huxley, 1899). Even to Huxley, it was evident that the body of knowledge called science was too big to be delivered, even in a simplified form, to all children:

*I do not mean that every schoolboy should be taught everything in science. That would be a very absurd thing to conceive, and a very mischievous thing to attempt. What I mean is, that no boy nor girl should leave school without possessing*



*a grasp of the general character of science, and without having been disciplined, more or less, in the methods of all sciences; so that, when turned into the world to make their own way, they shall be prepared to face scientific problems, not by knowing at once the conditions of every problem, or by being able at once to solve it; but by being familiar with the general current of scientific thought, and by being able to apply the methods of science in the proper way. (p. 71)*

What Huxley is arguing for here is what we now refer to as ‘How science works’, teaching children about how to differentiate between science and pseudoscience. How scientists work and how scientific arguments work is central to such a vision. He goes on to describe the foundation on which a science education should be built:

*I conceive the proper course to be somewhat as follows. To begin with, let every child be instructed in ... ‘physical geography’ [earth science/geology], that is to say, a general knowledge of the earth, and what is on it, in it, and about it. If anyone who has had experience of the ways of young children will call to mind their questions, he will find that so far as they can be put into any scientific category, they come under this head of ‘erdkunde’ [earth science]. The child asks, ‘What is the moon, and why does it shine?’ ‘What is this water, and where does it run?’ ‘What is the wind?’ ‘What makes the waves in the sea?’ ‘Where does this animal live, and what is the use of that plant?’ (p.71–72)*

Huxley’s vision is of an approach to science education that fulfils the two aims outlined in the BAAS report: an understanding of science (the process of science) and a basic pre-science training. Both of these aims, I contend, are relevant today. Huxley was a strong advocate of a practical approach to science education, as was H. E. Armstrong (1848–1937), who strongly advocated the teaching of ‘The Scientific Method’ (his term for practical enquiry-based methods) in schools, although at the time he felt that his appeal would not be supported by many science teachers (Armstrong, 1903).

In the influential *Beyond 2000* report on the future direction of science education, it was noted that one of the problems to be addressed was that ‘school science, particularly at secondary level, fails to sustain and develop the sense of wonder

*and curiosity of many young people about the natural world.’ (Millar and Osborne, 1998: 5)*

The report goes on to state that the science curriculum is more like a ‘catalogue’ of discrete ideas, with an over-emphasis on content, lacking context, and that the practice of science is not well taught. I would argue that a return to discrete compartmentalised content in three areas, biology, chemistry and physics, will not address the issues highlighted. In my opinion, awe and wonder in science comes from seeing the interrelatedness of chemistry, physics, biology, geology and astronomy and is derived from ‘the big ideas and concepts’ (for example, evolution, deep time, etc.), drilling down into the detail. It does not come from the detail, which can be difficult for pupils to build up into the ‘big ideas’.

## Conclusion

There is currently a concentration on the separate science disciplines when it comes to the recruitment of graduates into teacher education. The most recent call for more specialist teachers of chemistry and physics is being backed with financial inducements to graduates of these disciplines over graduates in biological or even Earth sciences. Even higher bursary payments will be awarded to chemists and physicists with good degree classifications (Department for Education, 2011). Although graduates from a variety of science disciplines are recruited to teacher education, the imposed specialisms and the requirement for training providers to categorise and deliver programmes that result in chemistry, physics and ‘other’ science teachers ignores the fact that, in the state-maintained education system, science teachers, first and foremost, deliver all science disciplines and rarely teach only their specialism at GCSE.

Good science teachers relate science content to other disciplines, including those outside the ‘traditional three’ sciences. There are many more degree titles than simply Biology, Chemistry and Physics, yet we seem to be clinging on to these as if the route from school to university science and into a productive world-leading workforce is a simple choice of one out of three disciplines. The multitude of options within science degrees in the UK alone means that no degree, regardless of its title, will necessarily cover all the areas required to teach that specialism to A-level. Science graduates entering teacher education

are required to widen their knowledge base and embrace all science disciplines. There is, however, reluctance from some specialists to embrace other disciplines (Maddern, 2011). The current Government focus for teacher recruitment is for specialist teachers with high academic qualifications. This is their preferred route to improving uptake of science post-16 and combating the dearth of specialist teachers in schools. Research also shows that high academic achievement is not necessarily the best predictor of teaching ability (Baskin, Ross and Smith, 1996; Byrnes, Kiger and Shechtman, 2003).

Those who enter teacher education often have a wide variety of knowledge and skills in a wide range of science and science-related disciplines. At Sussex University, over the past 6 years, graduates from a variety of science disciplines have entered teacher education. From equine studies, neuroscience, psychology, physics with astrophysics to oceanography and genetics, entrants to science teaching have had to adapt and attain a range of science subject knowledge as well as pedagogic knowledge suited to teaching school science.

We must acknowledge that better uptake to post-16 STEM courses will not be achieved simply through the teaching of separate science disciplines to all. In a sense, we tried that approach and it failed. The vast majority of students will not study sciences beyond the age of 16, so devotion to separate sciences seems odd. Surely better teaching of 'natural sciences' by science graduates trained to deliver across the disciplines would better serve the majority of pupils?

Perhaps we must acknowledge explicitly what happens implicitly, that one of the jobs of the science teacher is to recognise the inherent love and aptitude for science that some pupils have. Once recognised, a system of nurture to guide such pupils to the study of science post-16 and into university education would be more profitable than a 'one-size-fits-all' science education. For the remaining students, Huxley's ideal of '[boys and girls] *possessing a grasp of the general character of science*' (Huxley, 1899) is what we could define as being scientifically literate and a satisfactory endpoint for a general science education for the majority of pupils.

From the ages of 5 to 16, a multidisciplinary approach is needed that takes a 'whole-world' perspective of science. Aspects of geology, biology,

astronomy, chemistry and physics, with the associated mathematical skills, must be delivered by teachers of science, working with teachers of mathematics, trained not just within their own discipline but across the various disciplines. Perhaps we need a mindset in our training of science teachers that goes beyond the subject specialism and sees the delivery of science in a holistic way. Yet those self-same teachers also need to maintain a subject specialism, perhaps through specialist early professional development (EPD). That specialism will come into its own when teaching post-16 science, preparing pupils for further and/or higher science education. To achieve this in the current climate of a short 36 week training programme will be very difficult. Science teacher education, rather than concentrating on the development of one key specialism, should encourage science graduates to gain a holistic sense of science – the 'natural sciences'.

### A way forward?

Perhaps the most productive way forward in science teacher education would be to reconsider the length of training. The development of more rounded teachers (where the physicist can feel just as comfortable teaching key stage 3 (age 11–14) or 4 (age 14–16) biology, chemistry or geology as physics) should be our goal, rather than sticking to a short training period with little or no time for the development of subject knowledge. An 18 month, or, better still, 2 year programme could deliver such subject knowledge input. With the advent of subject knowledge enhancement courses before teacher training, we have embarked on a better and more sustainable model of science teacher preparation, but even these are concentrated in chemistry and physics, yet again marginalising the 'other' sciences.

A 2 year programme may appear to be unfeasible – would graduates wish to spend 2 years in training? Can the Government support a 2 year training programme? Would high fees put off good graduates from entering teaching if it meant adding another £18,000 to their student debt (assuming a £9,000 fee for a PGCE)? If we are creative and look upon the training as part academic (1 year attracting fees) and part professional (attracting bursaries for in-school training and subject knowledge acquisition), it could be an attractive professional option for highly qualified graduates. A 2 year programme that delivered core

science subject knowledge and core pedagogic knowledge and understanding, with an extended time in schools as a licensed (though not fully qualified) teacher who is supervised but allowed more freedom to be in sole charge of a class, could

deliver a better training and education package leading to better prepared teachers.

### Note

In the UK many long-established private schools are often referred to as 'public schools' (for example, Eton, Harrow and Rugby).

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